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1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE	3. REPORT TYPE AND DATES COVERED Summary 01 Oct 93 - 31 May 94	
4. TITLE AND SUBTITLE Ultrasonic Characterization of High $T_c$ and Other Unconventional Superconductors			5. FUNDING NUMBERS PE 61153N N0014-91-J-1211 TA 3126946 --- 10	
6. AUTHOR(S) Moises Levy			7. PERFORMING ORGANIZATION REPORT NUMBER	
8. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Physics Department University of Wisconsin-Milwaukee Milwaukee, WI 53201			9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research ONR 331 800 North Quincy Street Arlington, VA 22217-5660	
10. SUPPLEMENTARY NOTES			11. SPONSORING / MONITORING AGENCY REPORT NUMBER 94-24114 	
12a. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; Distribution unlimited			12b. DISTRIBUTION CODE 94 7 29 048	
13. ABSTRACT (Maximum 200 words) Ultrasonic techniques have been used to characterize properties of high $T_c$ and other unconventional superconductors. Attenuation and velocity measurements with shear waves have been performed on a sintered sample of $HgBa_2CuO_x$ and single crystal and melt textured samples of YBCO as a function of magnetic field. Anomalous behavior is observed which may be due to the fact that sound waves are sensitive to the total number of flux lines sampled, regardless of their orientation. A pontoon technique was used to launch surface acoustic waves SAW through a single crystal platelet of YBCO. A relative maximum in attenuation is observed at around 90K which may be associated with a relaxation process. Measurements on a SAW reflective array compressor made of superconducting YBCO appear to indicate that the YBCO reflecting chevrons are more effective in reflecting the SAW in the normal state than in the superconducting state. The insertion loss of a SAW delay line made with YBCO interdigital electrodes decreased when the electrodes became superconducting. A theoretical model has been developed to quantitatively explain these results. DTIC QUALITY INSPECTED 8				
14. SUBJECT TERMS YBCO, $HgBa_2CuO_x$ , Shear Waves, Surface Acoustic Waves, High $T_c$ Superconductors, Unconventional Superconductors, SAW delay line, SAW reflective array compressor			15. NUMBER OF PAGES 8	
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18. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	19. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	20. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	21. LIMITATION OF ABSTRACT	

## ANNUAL SUMMARY REPORT

OCTOBER 1, 1994 TO MAY 31, 1994

## A. Description of Project

The objectives of this research project are to characterize the properties of high  $T_c$  superconductors and other unconventional superconductors using ultrasonic techniques in order to provide insights into the mechanisms that are responsible for the unusual superconducting properties of high  $T_c$  superconductors.

## B. Approaches Taken

Bulk acoustic wave attenuation and velocity measurements as a function of temperature and magnetic field are in progress on melt textured and single crystal samples of  $Y_1Ba_2Cu_3O_7$ , on a sample of the newly discovered Hg based high  $T_c$  superconductor, and on an excellent single crystal of  $(La_{0.875}Sr_{0.125})_2CuO_4$ .

Ultrasonic attenuation and velocity measurements on the heavy Fermion superconductor  $UPt_3$  are in progress in the high magnetic field facility at the Max Planck Institute in Grenoble, France.

A pontoon technique has been developed to launch surface acoustic waves across a single crystal platelet of  $Y_1Ba_2Cu_3O_7$ .

The change in insertion loss at the superconducting transition of a surface acoustic wave SAW delay line whose interdigital electrodes are made of a film of  $Y_1Ba_2Cu_3O_7$  has been determined. Preliminary observations have been made on an  $Y_1Ba_2Cu_3O_7$  SAW reflective array compressor above and below the superconducting transition temperature.

Availability Codes	
Dist	Avail and/or Special
A-1	

All the components for the resonant ultrasonic spectrometer station, which comprises the spectrometer, and the cryogenic station have been received and are being assembled. Sample holders and support structures have been designed and are being machined in our machine shop.

All components for the ZnO sputtering station have been received and are being assembled. Electron guns and sample holders have been designed and are being machined in our machine shop.

### C. Accomplishments

Attenuation and velocity measurements on a melt textured sample of  $Y_1Ba_2Cu_3O_7$  obtained from Donglu Shi, Argonne National Laboratory, were made as a function of magnetic field in the superconducting state. Both the attenuation and velocity increase or remain constant as the magnetic field is increased or decreased or reversed in sign until a saturated value is obtained which depends upon the maximum value of the magnetic field being applied. Similar results were observed on two single crystal samples of  $Y_1Ba_2Cu_3O_7$  obtained from Yao Liang, University of Cambridge, and a sintered sample of  $HgBa_2CuO_4$  obtained from David Hinks, Argonne National Laboratory. This anomalous behavior may be explained by noting that the penetration of flux lines into the sample appears to depend on the log of time, so that when the field is decreased flux lines are still migrating from the surface into the inner volume of the sample, thus increasing the number of flux lines sampled by the sound waves. When the magnetic field is reversed, oppositely oriented flux lines enter the sample, but do not annihilate the first set of flux lines. Thus the net magnetization may decrease, but since the sound waves are sensitive to the number of flux lines but not their orientation, both the attenuation and velocity increase. A manuscript is being prepared to report these results.

Surface acoustic wave attenuation measurements at 160 MHz were made on a platelet of  $Y_1Ba_2Cu_3O_7$  obtained from George Crabtree, Argonne National Laboratory. Three relative

maxima in attenuation are observed, with one centered at about 90 K. This latter appears to be a relaxation maximum.

The superconducting surface acoustic wave reflective array compressor investigated consists of two pairs of broad band interdigital electrodes placed next to each other. Each pair has a transmitting electrode at one end and a receiving electrode at the other. Metallized chevrons at a  $45^\circ$  angle are deposited between the transmitting electrodes and the receiving ones. The spacing between the chevrons is such that different wavelength SAW are reflected at different distances from the transmitting electrodes. The chevrons along each pair or channel are mirror images of each other. In proper operation, SAW at a particular frequency may be reflected by chevrons a third of the way along one channel to the other channel and then returned back to the interdigital electrodes in the second channel. We obtained unusual results with such a device whose chevrons and interdigital electrodes were made of superconducting  $Y_1Ba_2Cu_3O_7$ . It is usually assumed that the reflectivity of the chevrons improves as their electrical conductivity increases. However, what we observed was that the transmission along the channel increased when the device was in the superconducting state. This device was made by Hans Fredricksen, University of Houston. New devices are being made where the interdigital electrodes are made of Al and the reflecting chevrons are made of  $Y_1Ba_2Cu_3O_7$  in order to isolate the effect and verify the observations.

The insertion loss of SAW delay lines made with  $Y_1Ba_2Cu_3O_7$  interdigital electrodes operating at 50 MHz and 100 MHz was reduced when the electrodes became superconducting. A model has been developed to quantitatively explain these results. A paper has been published in Applied Physics Letters (B3) describing these results.

**OFFICE OF NAVAL RESEARCH  
PUBLICATION/PATENTS/PRESENTATION/HONORS REPORT  
for**

1 Oct 93 through 31 May 94

R&T Number: 312946 --- 10

Contract/Grant Number: N00014-91-J-1211

Contract/Grant Title: Ultrasonic Characterization of High  $T_c$  and Other  
Unconventional Superconductors

Principal Investigator: Moises Levy

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- a. Number of Papers Submitted to Referred Journal but not yet published: 2
- b. Number of Papers Published in Referred Journals: 4  
(list attached)
- c. Number of Books or Chapters Submitted but not yet Published: 3
- d. Number of Books or Chapters Published: 0  
(list attached)
- e. Number of Printed Technical Report & Non-Referred Papers: 3  
(list attached)
- f. Number of Patents Filed: 0
- g. Number of Patents Granted: 0  
(list attached)
- h. Number of Invited Presentations at Workshops or Prof. Society Meetings: 3
- i. Number of Presentation at Workshop or Prof. Society Meetings: 4
- j. Honors/Awards/Prizes for Contract/Grant Employees:  
(list attached, this might include Scientific Sec. Awards/Offices,  
Promotions, Faculty Award/Offices etc.)
- k. Total number of Graduate Students and Post-Docs Supported at least 25%, this  
year on this contract, grant:  
Grad Students 5 and Post Docs 1
- |    |                        |               |
|----|------------------------|---------------|
| [  | Grad Student Female    | <u>1</u>      |
| ][ |                        |               |
| [  | Grad Student Minority  | <u>      </u> |
| ][ |                        |               |
| [  | Grad Student Asian e/n | <u>2</u>      |
| ][ |                        |               |
| [  | Post-Doc Female        | <u>      </u> |
| ][ |                        |               |
| [  | Post-Doc Minority      | <u>      </u> |
| ][ |                        |               |
| [  | Post-Doc Asian e/n     | <u>      </u> |
| ][ |                        |               |
- How many of each are females or minorities?  
(These & numbers are for ONR's EEO/Minority  
Reports; minorities include Blacks, Aleuts  
Amindians, etc and those of Hispanic or  
Asian extraction/nationality. This Asians  
are singled out to facilitate meeting the  
varying report semantics re "under-  
represented")

OFFICE OF NAVAL RESEARCH  
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT  
1 October 1993 through 31 May 1994

- a. Number of Papers Submitted to Referred Journals but not yet published: 2
  1. "Ultrasonic Investigation of Amorphous Superconducting Films," J. Schmidt, M. Levy and A. F. Hebard, Phys. Rev. (to be published).
  2. "Ultrasonic Studies of Superconducting Phase Diagram of  $UPt_3$ ," S. W. Lin, H. Zhang, C. Jin, J.B. Ketterson, D. M. Lee, D. G. Hinks, M. Levy and B. K. Sarma, Physica B (to be published).
- b. Number of Papers Published in Referred Journals: 4
  1. "Ultrasonic Determination of the Superconducting Energy Gap in Domain Boundaries of Melt-textured  $Y_1Ba_2Cu_3O_7$ ," Moises Levy, Zheng-Xiao Li, Bimal K. Sarma, S. Salem Sugui, Jr. and Donglu Shi, Philosophical Magazine Letters, 68, 147-154 (1994).
  2. "Superconducting Phase Diagram of  $UPt_3$  for Fields Along a Nonsymmetric Orientation from Ultrasonic Measurements," S. W. Lin, C. Jin, H. Zhang, J. B. Ketterson, D. M. Lee, D. G. Hinks, M. Levy and Bimal K. Sarma, Phys. Rev. B 49, 10,001-10,004 (1994).
  3. "High Transition Temperature Superconducting Surface Acoustic Wave Devices," H. Fredricksen, D. Ritums, N. J. Wu, S. Y. Li, A. Ignatiev, J. Feller, B. K. Sarma and M. Levy, Appl. Phys. Letters 64, No. 22 (30 May 1994).
  4. "BCS Temperature-Dependent Superconducting Energy Gap in Domain Boundaries of Melt-Textured  $Y_1Ba_2Cu_3O_7$ ," M. Levy, Z.-X. Li, B. K. Sarma, S. Salem-Sugui, Jr. and D. Shi, Journal of Superconductivity 7, 409-414 (1994).
- c. Number of Books or Chapters Submitted But Not Yet Published: 3
  1. "Surface Acoustic Wave Measurements on Superconducting Films," M. Levy and S. Schneider (chapter to be published in Mechanical Spectroscopy, editor L. B. Magalas, publisher Elsevier Science Publishers Ltd.)
  2. "Surface Waves in Solids and Ultrasonic Properties," Moises Levy and Susan C. Schneider, Handbook of Acoustics, Edited by Malcolm J. Crocker. (To be published by John Wiley & Sons, Inc.)

3. "Multiple Superconducting Phases and Unconventional Superconductivity in  $UPt_3$ ," Bimal K. Sarma, S. W. Lin, M. Levy, S. Adenwalla, and J. B. Ketterson, Proceedings of the S. N. Bose Centenary Celebration (edited by M. Dutta).
- e. Number of Printed Technical Reports and Non-Referred Papers: 3
1. "Superconducting Energy Gap in Domain Boundaries of Melt Textured  $Y_1Ba_2Cu_3O_7$ , From Low Magnetic Field Ultrasonic Measurements," Moises Levy, Zheng-Xiao Li, Bimal K. Sarma, S. Salem Sugui, Jr. and Donglu Shi, 793-798, IEEE 1993 Ultrasonics Symposium Proceedings, (93 CH 3301-9 Edited by B. R. McAvoy and M. Levy, IEEE, New York, 1993).
  2. "Temperature Dependence of Ultrasonic Attenuation in the Superconducting State of the Heavy Fermion Compound  $UPt_3$ ," H. Zhang, S. W. Lin, M. Levy, B. K. Sarma, C. Jin and D. M. Lee, 799-802, IEEE 1993 Ultrasonics Symposium Proceedings, (93 CH 3301-9 Edited by B. R. McAvoy and M. Levy, IEEE, New York, 1993).
  3. "Superconducting Phase Diagram of  $UPt_3$  For Field Along Non-Symmetric Orientation from Ultrasonic Measurements," S. W. Lin, C. Jin, H. Zhang, J. B. Ketterson, D. M. Lee, D. G. Hinks, M. Levy, and Bimal K. Sarma, Physica B, Vols. 194-196, pgs. 2023-2024 (1994).
- f. Number of Patents Filed: 0
- g. Number of Patents Granted: 0
- h. Number of Invited Presentations at Workshops or Professional Society Meetings: 3
1. "Ultrasonic Determination of the Superconducting Energy Gap in Domain Boundaries of Melt-Textured  $Y_1Ba_2Cu_3O_7$ ," M. Levy, 1993 Ultrasonics Symposium, Baltimore, Maryland, October 31 - November 3, 1993.
  2. "Ultrasonic Determination of the Superconducting Energy Gap in Domain Boundaries of Melt-Textured  $Y_1Ba_2Cu_3O_7$ ," M. Levy, International Symposium on Mathematical Physics, Calcutta, India, January 1-7, 1994.
  3. "Multiple Superconducting Phases and Unconventional Superconducting in  $UPt_3$ ," B. K. Sarma, International Symposium on Mathematical Physics, Calcutta, India, January 1-7, 1994.
- i. Number of Presentations at Workshops or Professional Society Meetings: 4
1. "High Resolution Velocity Measurements in the Superconducting State of the Heavy Fermion Compound  $UPt_3$ ," S. W. Lin, H. Zhang, M. Levy, B. K. Sarma, C. Jin and D. M. Lee, 126th Meeting of the Acoustical Society, Denver, Colorado, October 4-8, 1993.

2. "Temperature Dependence of Ultrasonic Attenuation in the Superconducting State of the Heavy Fermion Compound  $UPt_3$ ," S. W. Lin, H. Zhang, M. Levy, B. K. Sarma, C. Jin and D. M. Lee, IEEE 1993 Ultrasonics Symposium, Baltimore, Maryland, October 31-November 3, 1993.
  3. "Superconducting Phase Diagram of  $UPt_3$  for Field Along Non-Symmetric Orientation From Ultrasonic Measurements," S. W. Lin, C. Jin, H. Zhang, J. B. Ketterson, D. M. Lee, D. G. Hinks, M. Levy and Bimal K. Sarma, LT20, 20th International Conference on Low Temperature Physics, Eugene, Oregon, August 4-11, 1993. Poster. (Not reported in 1993 P<sup>3</sup>H.)
  4. "Ultrasonic Studies of Superconducting Phase Diagram of  $UPt_3$ ," S. W. Lin, H. Zhang, C. Jin, J. B. Ketterson, D. M. Lee, D. G. Hinks, M. Levy and B. K. Sarma, International Conference on Strongly Correlated Electron Systems, LaJolla, California, August 16-19, 1993. (Not reported in 1993 P<sup>3</sup>H.)
- k. Total Number of Graduate Students and Post Docs Supported at Least 25%, This Year On This Grant:
- |                      |               |
|----------------------|---------------|
| Graduate Students: 5 | Post Docs: 1  |
| Debashis Dasgupta    | Mark Mackenna |
| Jeff Feller          |               |
| Ron Gaffney          |               |
| Joseph Herro         |               |
| Hong Zhang           |               |

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